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Microcomputer Control of Infrared Detector Arrays

Prepared by

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THE AEROSPACE CORPORATION

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ABSTRACT

A microcomputer-based data acquisition system has been developed for astronomical observing with two-dimensional infrared detector arrays. The hardware used is a 16-bit, 8086/8087-based system operating at 8 MHz. Data rates of up to 454,000 pixels/sec are supported. The hardware is operated using interactive software which supports several modes of data acquisition.

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ACKNOWLEDGMENTS

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I. INTRODUCTION

The Infrared Astronomy Group at The Aerospace Corporation is currently involved in a program of 10-μm observations using infrared detector arrays. This program entails the use of two 16-column by 32-row detector arrays manufactured by Aerojet Electro-Systems Corporation, and one 10-column by 50-row detector array manufactured by Rockwell International. In addition to the arrays, each manufacturer has provided the analog signal chain electronics, multiplexers, and analog-to-digital converters needed to interface the arrays to a digital data acquisition system. In this report, the microcomputer hardware used to record the array outputs and the software used with that hardware will be described. The hardware is an extension of the microcomputer system used in our spectroscopic observing programs. A complete description of that hardware and the interactive software used with it can be found in Rossano (1986).* As with our spectroscopic instruments, the array systems are designed for use on the NASA Lear Jet and Kuiper C-141 airborne astronomy facilities. The need for a rugged, reliable, and flexible system operated in an airborne environment again has a major impact on hardware and software design.

*Rossano, G. S., Publ. Astron. Soc. Pac., 1986, to be published.

II. HARDWARE

The three detector arrays are free running systems that output the detector values as 12-bit words in a raster like, left to right, top to bottom sequence. The arrays continuously sequence through all detectors at a user selectable frame rate. The maximum frame rate (minimum frame time) is fixed by a minimum pixel time of 600 nsec. The digital outputs from the Aerojet arrays are 12-bit binary values whose range of 0 through 4095 corresponds to an analog voltage of 0 through 4.999 V (4096 corresponds to 5 V). The digital output from the Rockwell array consists of a 10-bit binary value whose range of 0 through 1023 corresponds to an analog voltage of 0 through 9.990 V (1024 corresponds to 10 V). The 11th bit is used to indicate the value of a manually selectable detector gain, whereas the 12th bit is not used. In addition to the 12 bits that encode the detector outputs, each array system outputs two timing signals. One of these is a pixel clock with a 50-percent duty cycle. The other is a frame sync signal. The pixel clock is active low when the data from the detector outputs are valid. The frame sync is active low for one-half of a pixel time when the data from the last pixel of the array is output, thus indicating the end of each detector array frame. The exact timing relationship between the data lines, pixel clock, and frame sync that defines our array interface standard is shown in Figure 1.

The microcomputer used to record the digital array outputs is an extension of the system used with our spectroscopic instruments. To record the array outputs we have added three items of hardware to the microcomputer system described in Rossano (1986). These three items are of a frame grabber, a color graphics display system, and a nine-track tape drive system.

The array outputs are sampled using a double-buffered frame grabber designed and built in the Space Sciences Laboratory of The Aerospace Corporation. Frames sizes up to 4096 pixels can be accommodated with the current hardware. In a double-buffered system the array outputs are stored in one buffer whereas the CPU accesses the other, previously filled, buffer. Once the CPU is finished accessing its current buffer the role of the two

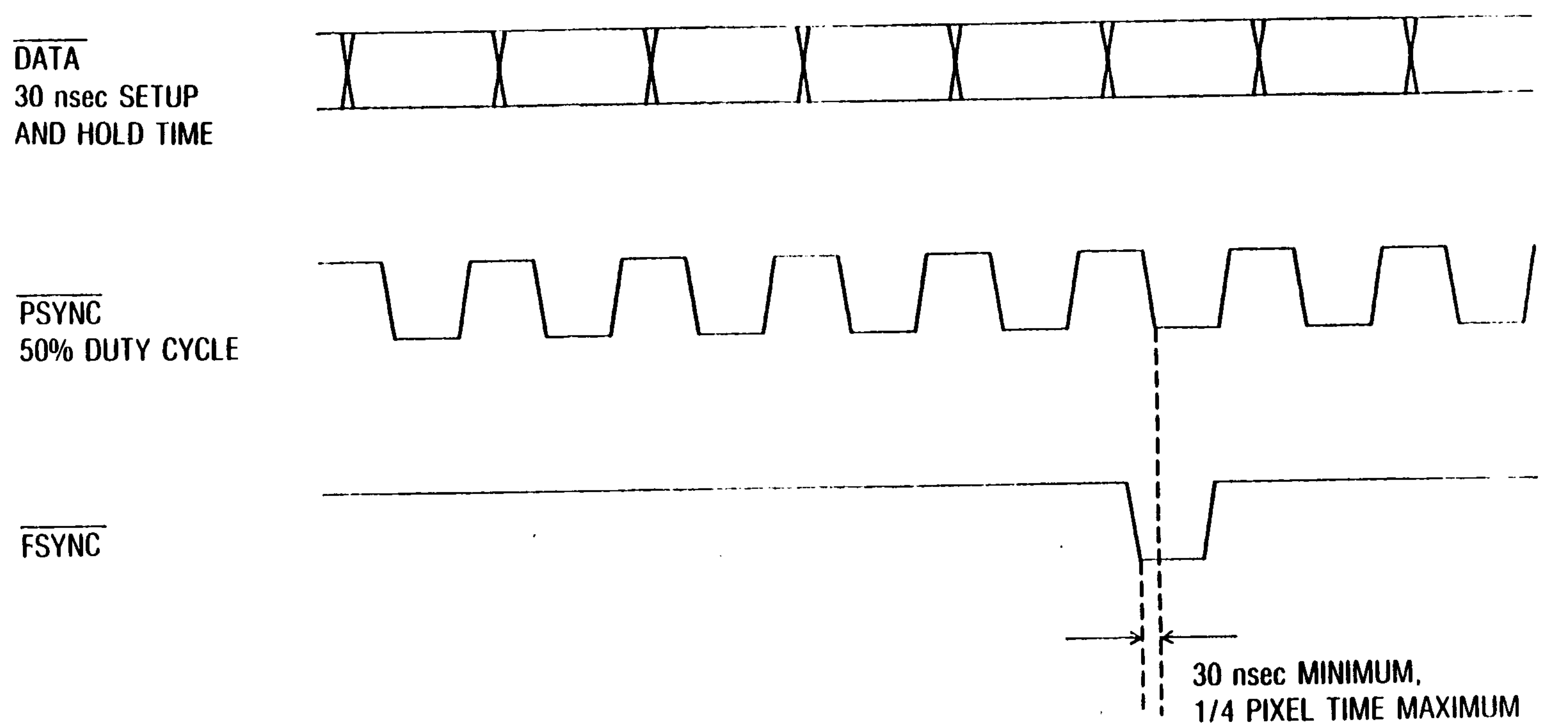

Figure 1. Timing relationships for digital array outputs.

hardware buffers is automatically reversed. As long as the CPU data transfer rate exceeds the array data rate no data will be lost as the CPU transfers data from the frame grabber to system memory. If, however, the array data rate exceeds the CPU data transfer rate, a certain number of frames will be periodically missed. An 8086 microprocessor operating at 8 MHz can execute memory-to-memory block transfers at a maximum rate of 454 K words/sec (2.2 μsec per transfer). Since the arrays can operate at rates up to 1.67 M words/sec, our system can only record one out of four frames when the arrays are operated at full speed. In order to keep track of the time sequence of frames recorded, the frame grabber keeps a running modulo-16 count of the array frame sync pulses. This 4-bit count is combined with the 12-bit array output to fill out the 16-bit words which are recorded.

The output of the detector arrays is displayed using a color graphics display system designed and built in the Space Sciences Laboratory. The display system is a dual image plane system which uses two Texas Instruments 9118 video display processor (VDP) chips. Each image plane uses a 9118 VDP chip with 16K bytes of memory. One VDP acts as a master controller, whereas the other acts as a slave controller. The display from the master controller can be programmed to overlay the display from the slave controller under software control. Each image plane can be independently manipulated and is programmable using several graphics modes. When used with the array systems the detector outputs are displayed on the slave image plane. The display resolution is 48 rows by 64 columns. Each pixel value is represented by one of 15 colors. The master image plane is software configured as a 192 row by 256 column display. The master image plane currently displays time and date information which overlays the slave image plane. The output from the graphics controllers is displayed on standard color video monitors. When operating on the Lear Jet facility a small 5-in. monitor is used. On the Kuiper Airborne Observatory a 19-in. monitor is used. Since the output from the graphics display system is NTSC composite video, we are able to record the graphics display on a video cassette recorder. When observing on the Kuiper facility, a stereo VHS video cassette recorder is used. The two audio channels of the VCR are used to record the two communications channels in the

Kuiper facility. The video tapes are an extremely valuable record of activities during an observing flight.

In order to avoid saturation of the detectors by a large infrared background, we are forced to operate the arrays at full speed. As a result, our typical data rate is 1.67 M words/sec. Co-adding this data and storing the averaged results on disk are relatively simple. However, nonastronomical program constraints require the recording of individual frames. The high data rates produced by the detector arrays, together with program requirements which necessitate the recording of individual array frames, place a severe strain on data recording techniques. When operated at full speed the arrays generate 12 billion bytes of data/hr of observing. Five hours of data acquisition over a night of observing thus generates 60 billion bytes of data. Using our current frame grabber only one quarter of that data can be recorded, which is still a considerable challenge.

Several methods of data recording are available in our hardware system. The simplest of these is recording on double-sided, double density 8-in. floppy disks. Each disk has a capacity of 1228 frames. At a frame time of 307 μsec (600 nsec/pixel times 512 pixels), 1228 frames correspond to 0.377 sec of integration time per detector. These data are collected in 1.5 sec of real time since only every fourth frame is captured by the frame grabber when the arrays are operated at full speed. In addition, approximately 30 sec is required to write the data, which is buffered in memory, to disk. Consequently, the observing efficiency when recording data on disk is approximately 1 percent when the arrays are operated at full speed. In addition to poor observing efficiency, recording on floppy disks has the disadvantage of requiring the use of an excessive number of disks. When recording on disk, disk consumption rates of up to 100 disks/hr are conceivable. Consequently, this method is generally neither cost-effective nor practical. Nevertheless, in certain situations its use cannot be avoided. For example, recording on disk is the only proven method for which the required hardware will fit into the limited space of the Lear Jet facility.

In order to improve observing efficiency and to eliminate the need to carry cases of floppy disks on each observing run, a relatively small nine-track tape drive was added to the microcomputer system for use on the Kuiper Airborne Observatory and during ground-based observing. The tape drive is a Telex 6250 bpi vacuum column drive which runs at 50 ips. Some tape drives require mechanical adjustments over the range of cabin air pressures encountered when operating on the Kuiper facility between sea level and operating cabin altitude (approximately 9000 ft pressure altitude). The drive selected does not require any such adjustments and was selected primarily for that reason.

The tape drive controller used to operate the tape drive was designed and built in the Space Sciences Laboratory. The controller is memory mapped and can support tape block lengths of up to 64K bytes. The controller makes the tape drive appear to the microprocessor as a 64K block of memory. Data transfers consist of an I/O-mapped command to the tape drive to read or write a tape block, followed by a memory-to-memory block data transfer. The tape controller forces CPU wait states, which synchronize the memory-to-memory data transfers with the tape drive data rate (312,500 bytes/sec). When recording on tape, data are buffered in memory and written to tape using a file structure of 50 64K byte blocks per file. Each file consists of 3200 frames. Up to 50 files can be recorded on each nine-track tape. The 3200 frames recorded in each data file correspond to 0.983 sec of integration time per detector. These data are collected in 3.9 sec of real time, since only every fourth frame is captured by the frame grabber when the arrays are operated at full speed, and require approximately 11 sec to be written to tape. The resulting observing efficiency when recording on nine-track tape is 6.6 percent when the arrays are operated at full speed. When recording on tape, tape consumption is no more than 4 tapes/hr.

The poor observing efficiency obtained when recording on floppy disk or nine-track tape is primarily caused by the low data transfer rates available with those devices. The use of hard disks or higher speed tape drives does not appreciably improve observing efficiency and does not meet our requirements for rugged portable equipment capable of operating in an airborne environment. Currently we are considering replacing our frame grabber with a DMA controller capable of capturing every frame when the arrays are operated at full speed, and to add a 1G byte optical disk system. With this hardware we anticipate an observing efficiency of 14 percent. This translates into 8.4 billion bytes of data in 5 hr of real time, recorded on 5 double-sided optical disks. In addition, this hardware is sufficiently compact so as to allow its use on the Lear Jet facility.

Extremely sophisticated and expensive mass storage devices are required to capture and store 5 hr of array data with the arrays operating at full speed with 100 percent efficiency. Currently we are involved in the development of a data acquisition system which directly records the array outputs of an Ampex 28-track high bit rate tape system. This system is capable of recording the array outputs at full speed with 100 percent efficiency without CPU intervention. Each 28-track tape is capable of storing 30 min of data when the arrays are operated at full speed. However, integrating this hardware into a data acquisition system is extremely difficult, time consuming, and expensive. The details of this hardware will not be described here due to its limited usefulness to the general observer.

III. SOFTWARE

The array outputs are displayed using the graphics system previously described. In the presence of a high background, and because of the significant pattern noise in the detector arrays, a direct frame-by-frame display of the detector outputs is of limited usefulness when observing in a staring mode. To overcome these problems, two essential features are included in the display software. First, to improve the signal-to-noise ratio, the average of a group of frames can be displayed instead of the individual frames themselves. This provides a display with an adequate signal-to-noise ratio for the brightest objects in the sky; however, even with multiple frame averaging, the vast majority of sources cannot be seen in a staring observation mode without correction for pattern noise. Thus, to correct for pattern noise, a predetermined set of offset and gain correction factors can be applied to the detector outputs before display. These correction factors are derived for each pixel from data obtained by uniformly illuminating the arrays with radiation from extended sources at two different temperatures. In addition, background offsets obtained by observing nearby regions of "empty" sky can be used to operate in a staring with background subtraction mode. If the background does not vary too rapidly, this mode of operation permits the display of weaker sources in real time.

In the absence of offset and gain corrections, weak sources are best displayed by chopping against nearby sky. In this mode of operation measurements are alternately made on source and off source. A running average of the on-source, off-source, and difference frames is displayed by the color graphics system. By chopping, background offsets and pattern noise are largely eliminated from the difference display since the AC response of the detectors is fairly uniform across the arrays. By chopping in a north-south direction with an appropriate chopper throw and the source properly located off center, a point source can be made to appear as both a positive and negative signal in the difference frames (one above center and one below). In this way the factor of 2 in integration time that would otherwise be lost in chopping can be recovered. Our current software can drive the Kuiper chopping secondary mirror at frequencies up to 27 Hz.

Several formats are available when recording the array data. The array outputs are sampled by the frame grabber and buffered in memory. These data are then periodically written to double-sided, double density 8-in. floppy disks, or to nine-track tapes. In addition to the array data, header information consisting of the source name, array identification, data acquisition program identification, data start time and date, and data stop time and date are recorded. Disk storage is divided into two groups of two memory buffers of 307 frames each and one header record. Each tape file consists of 10 memory buffers of 320 frames each and one header record.

In addition to recording the raw detector outputs, averaged data can also be recorded. When observing in a staring mode, a user-defined number of frames can be averaged together and stored on disk as a map file. Each map file consists of 256 bytes of header information followed by the individual detector values in raster sequence. The detector values are the averages of the frames sampled, converted to output voltages. When observing in a chopped mode, a user-defined number of chopper cycles are averaged together and stored on disk. As is the case in the chopped display procedure, the on-source, off-source, and difference frames are averaged together. At the end of the desired number of chopper cycles, each of these averages is written to disk as a map file. The recording of averaged and/or chopped data is the procedure we normally use for astronomical observations. Observing efficiency is approximately 4 percent in the staring mode and 2 percent in the chopped mode when the arrays are operated at full speed. These observing efficiencies are limited primarily by the speed at which the 8086 can process the data in real-time. Data storage requirements in the staring and chopped modes are relatively modest, with a full night of observing requiring only one or two floppy disks. Observing efficiencies could be substantially improved by operating the arrays at lower speeds; however, the infrared backgrounds currently seen by the detectors preclude this operation.

Post-processing of recorded data is relatively straightforward. The individual frames recorded on disk or tape can be displayed in sequence using the same display format as previously described. The individual frames can be averaged together to produce a map file for each data file recorded on disk or tape. In addition, a map file consisting of standard deviations is also generated when the frames are averaged. Map files can be interactively manipulated in a variety of ways. The most basic of these consist of correction for offset and gain variations, display of the detector values, and listing of the detector values and standard deviations. Examples of data taken with a Rockwell and an Aerojet array in the chopped mode are shown in Figure 2.

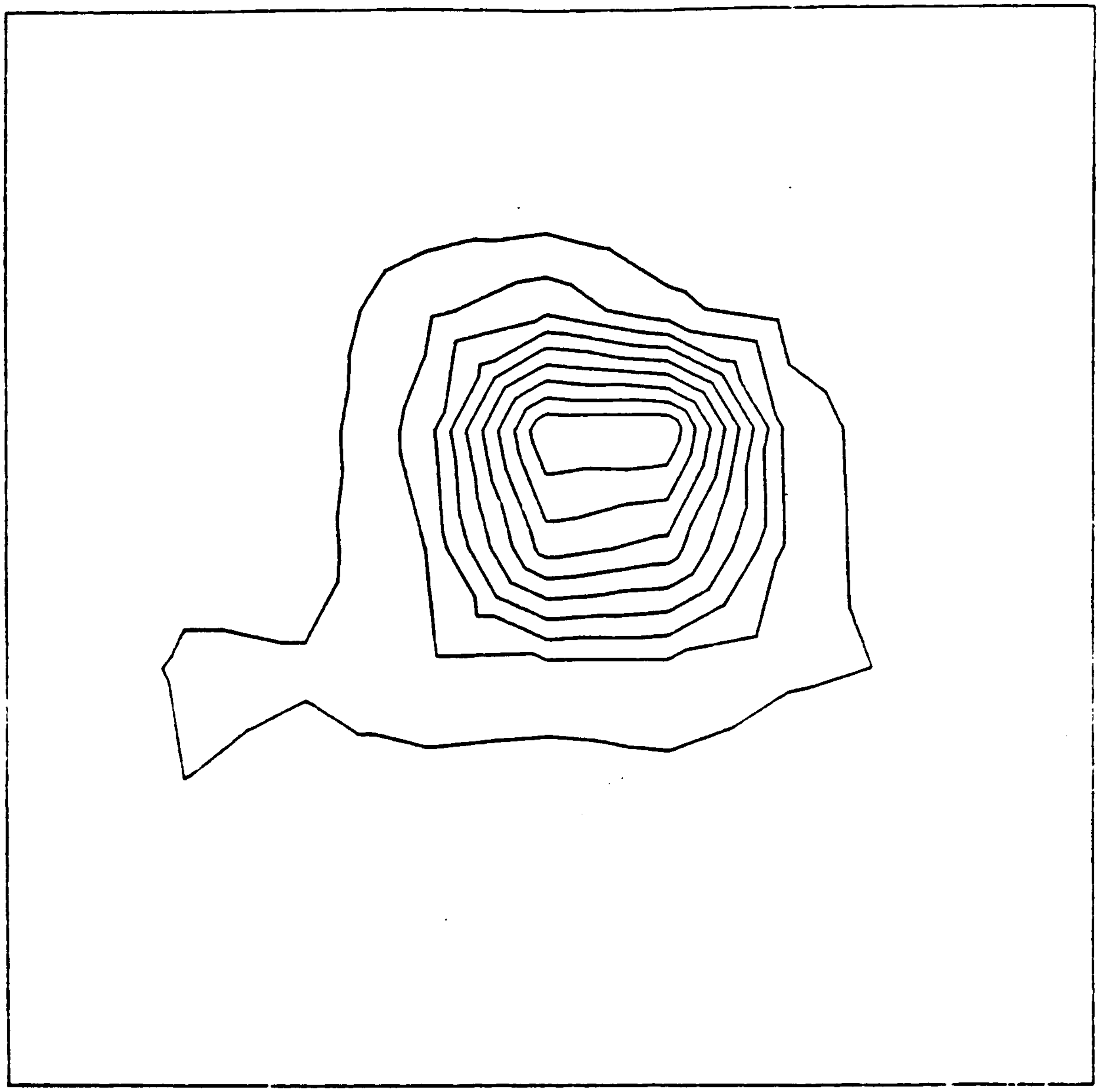

Figure 2a. 10-micron array observation of α Ori obtained on the Kuiper 36-in. telescope with a Rockwell array. The center 9 by 9 pixels are shown. The field of view is 45 by 45 arc sec. Contours are plotted every 3 mV. The result was obtained by averaging 4000 chopper cycles. Each cycle consists of data from one 307 μsec frame taken on source minus data from one 307 μsec frame taken off source. The FWHM observed for this point source is 11 arc sec.

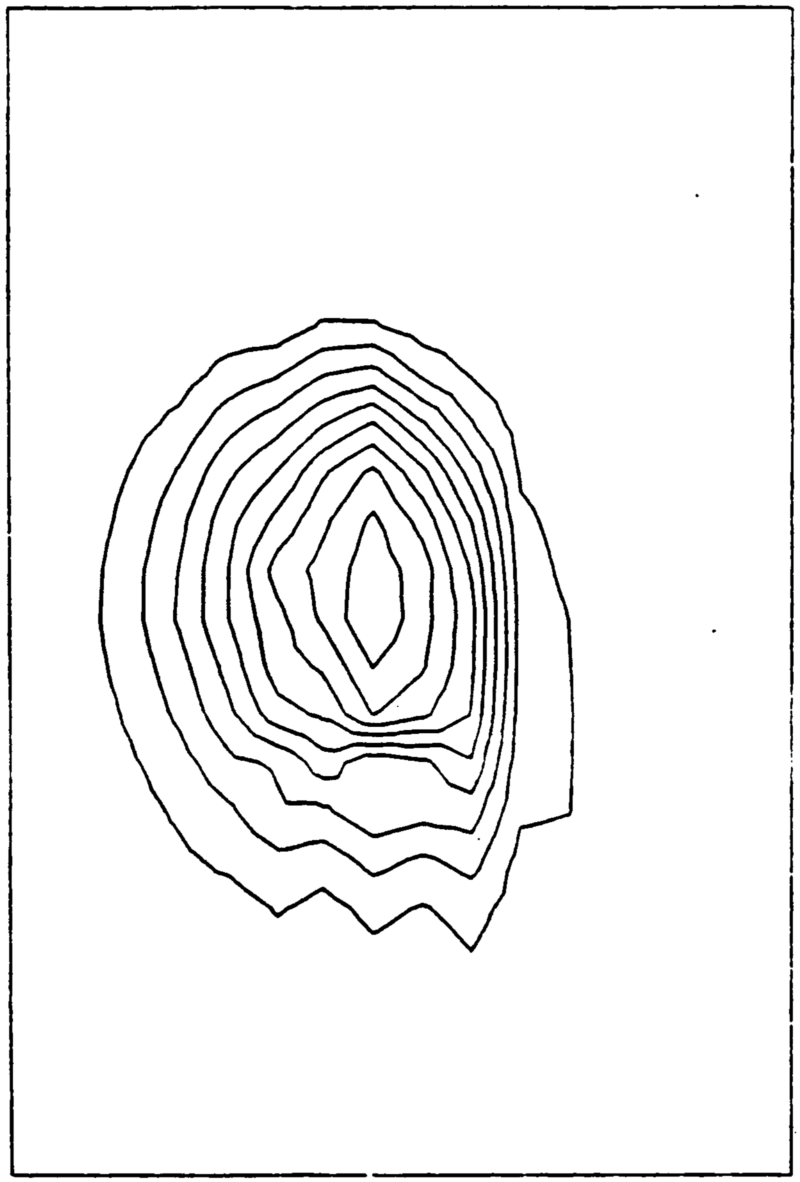

Figure 2b. 10-micron array observation of Venus obtained on the Kuiper 36-in. telescope with an Aerojet array. The lower 24 by 16 pixels are shown. The field of view is 120 by 80 arc sec. Contours are plotted every 63 mV. The data were obtained as above.

IV. SUMMARY

To facilitate the use of infrared arrays with a digital data acquisition system, we have established a digital signal and timing interface standard. Arrays built to this standard by two manufacturers have been interfaced to a microcomputer-based data acquisition system. These arrays have been used interchangeably on two airborne telescopes and one ground-based telescope. Interactive data acquisition software has been developed which supports several methods of observation and data recording. Sequential frames can be captured and recorded at output rates of up to 454 K pixels/sec. Data from arrays operated at rates of up to 1.67 M pixels/sec can be captured and recorded; however, sequential frames cannot be captured at that rate with our current hardware. Efforts are currently underway to improve observing efficiency by permitting acquisition of sequential frames at rates up to 1.67 M pixels/sec using an Ampex 28-track tape recorder, and, eventually, optical disk storage technology.